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RING DEPOSITS ON SURFACES BOMBARDED BY CANAL RAYS

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(Plates IA and IB)

ABSTBACT The paper deals with a detailed investigation on the formation of the deposits with the ring structure, obtained on surfaces, due to bombardment by positive rays, in the observation chamber of a canal ray tube of the usual simple type (when hydrocarbon substances are present in the discharge tube). The phenomenon has been studied as a function of the nature and condition of the surface bombarded, nature of the gas in the discharge tube, energy of the rays, time for which the bombardment takes place, etc. Special experiments are reported which were carried out to elucidate the mechanism of (1) the deposit formation, (2) origin and development of the ring structure. The results obtained have been finally discussed and a mechanism suggested for the deposit formation.

INTRODUCTION

The formation of deposits, in discharge tubes under different forms of discharge, has often proved of interest and has led to interesting results on the space distribution of the potential in the tube. The formation of deposits, on surfaces bombarded by canal rays in the observation chamber of a canal ray tube, takes place under conditions which are much simpler, as this space is free of the electric field. Black deposits are known to form on plates of glass or metal when bombarded by canal rays which have not been passed through an analysing field prior to the impact. An examination of these deposits by electron diffraction led Raether (1933) to ascribe them to carbon, produced from the decomposition of the hydrocarbon vapours usually present in the discharge tubes. That these deposits show a ring structure under certain circumstances was shown by Dasannacharya, Chiplonkar and Sapre (1934). As the phenomenon did not appear to have been investigated in sufficient detail, the following experimental work was undertaken which it is the object of the present paper to report.

The experimental arrangement used for this investigation (Chiplonkar, 1939 a) consisted of three canal ray units with modifications to suit the particular aspect of the problem in hand. The first one of these is 3.5 cms. in diameter with a cathode of brass faced with aluminium and a canal 20 mms. in length and 2 mms. in diameter. The anode is made of aluminium and is fitted in a side tube at a distance of 16 cms. from the cathode. The observation chamber is 10 cms. long and into this is introduced the material to be bombarded, which usually consisted of plates 15 cms. × 20 cms. on a metal carrier. This observation chamber is closed with a glass window fixed with sealing

wax. The second unit differs from the first in having a cathode of moulded aluminium 8 mms. long with a canal 2 mms. in diameter ; all the other measurements are identical. The third unit has a discharge tube 2.5 cms. in diameter with a canal 7.0 mms. long and 2 mms. in diameter. This is provided with ground joints at both its ends. Through one of these is introduced the material to be bombarded and through the other the anode.

Different gases were used in the discharge tube. The gases hydrogen and nitrogen were obtained from cylinders and were purified and dried by passing successively through alkaline pyrogallol and a train of drying tubes before being admitted into the apparatus. Oxygen and carbon-dioxide were obtained by heating pure potassium-permanganate and sodium-bicarbonate respectively in vacuum. Evacuation was obtained by means of a set of mercury diffusion pumps of the Waran type backed by a Cenco Hyvac oil pump. Liquid air traps were used for preventing the diffusion of mercury vapour into the discharge tube and when permissible for purifying the gases.

The H. T. voltage was obtained from a transformer coupled with a single Kenotron circuit. The anode was connected to H. T. the cathode being earthed through a milliammeter. The H. T. voltage was measured by means of an electrostatic voltmeter of the Kelvin-Whyte type. This potential, as well as the earth current, were kept constant by regulating the gas-pressure and the filament current of the Kenotron respectively. A wattmeter of the dynamometer type was introduced into the primary of the H. T. transformer; the constancy of the energy input to which, was ensured by maintaining the wattage reading constant throughout the course of the experiment.

In a series of experiments gas streaming was used. Apparently this made no difference in the final results.

EXPERIMENT AND RESULTS

The nature of the rings observed in the first instance coupled with Raether's observations suggested the presence of a hydrocarbon substance (which would ultimately serve as a source of carbon) as necessary for the deposit formation. This was confirmed by the observation that the intensity of the deposits increased enormously when picein was introduced in the discharge tube. The effect of introducing this in (1) the observation chamber, (2) the discharge chamber, was first observed. In the former the face of the cathode itself (away from the discharge side) was painted with picein; in the latter its vapour was mixed with the streaming gas. The behaviour of the deposits under the two modes of observation is quite different ; whereas in (1) only ten to twenty minutes sufficed for a visible deposit to appear, in (2) exposures of the order of 2-3 hours were required. The object of the experiment was to decide whether the association of the deposit forming particles with the main canal ray beam takes place in the observation or the discharge chamber. Later experiments revealed that the diffusion of the vapours from the observation to the discharge chamber, took place to an appreciable extent

although the direction of gas streaming was such as to oppose this. Merck's pure paraffin wax and iodine were also tried in place of piccin for painting the cathode. In the former copious amounts of carbon were released which escaped to the discharge side and were found to effect the main discharge in such a manner as to make it unsteady. The receptacle plate in this case showed only an ill-formed brown deposit. Iodine, on the other hand, was not found to form deposits as shown by microchemical tests.

The effect of variation of the nature and the condition of the bombarded plate was next investigated by successively exposing plates of aluminium, copper, mica, polished graphite (Pl. 2) ground glass (Pl. 1) to positive rays of hydrogen. In all these cases, except the last, sharp ring deposits were obtained. The rings are easier formed and better defined on the metals than on the non-metals. The ring pattern in all these cases with the above exception is essentially similar. The condition of the surface affects both the time for deposit formation as also the pattern, for the ground glass. One gets only a central transparent spot after long exposures—presumably corresponding to the spread of the positive rays, surrounded by a dark annular patch, the outer edge of which gradually fades in intensity. In some experiments, plates initially covered with soot (from sealing wax) were exposed to positive rays of hydrogen. In this case a central circular region was made bare by the impacting rays and at a distance of few millimeters from the edge of the central region a thin sharp ring grey in color was formed on the deposit already there.

Different gases like carbon dioxide (Pl. 3), oxygen (Pl. 4) nitrogen (Pl. 5) air (Pl. 26), mixture of hydrogen and nitrogen produced essentially the same ring pattern except nitrogen and oxygen. In the case of these latter, patterns are produced which are characteristic of the other gases with longer times of exposure and higher voltages (*vide infra*). The intensity of the deposits shows a certain dependence on the nature of the gas in the discharge tube appearing quickest with hydrogen and comparatively with less ease in the other gases in the order, nitrogen, oxygen, carbon dioxide and air. One might have expected them to appear quickest in carbon dioxide for the gas itself might be expected to supply the deposit-forming material. The above observation is supported by another experiment in which piccin was made to predominate in the discharge chamber (Pl. 14) when no great difference in the intensity of the deposits was brought about. The observation that they appear with the least ease in air suggested the possibility that its constituents might have mutually disturbing influence. It was shown by taking observations with a mixture of hydrogen and nitrogen that no such influence existed. Experiments were also made in which iodine and mercury were used in the discharge tube with traces of hydrogen. With mercury alone (without the presence of piccin) irregular deposits were obtained either on metallic or glass plates. The effect of temperature on the deposit formation was investigated by cooling the bombarded glass plate with liquid air. For this purpose, a vertical discharge tube was devised with a ground joint closing the observation chamber. This was partly filled

with mercury, the level coming to within a distance of 6-7 cms. from the cathode. On the mercury surface was placed the glass plate and liquid air was applied over the whole of the mercury column. Again no change in the density of the deposits was observed. All these observations taken together show that the deposit formation is not merely a condensation of the deposit-forming material but is a process intimately connected with discharge reactions taking place on the other side of the canal.

The deposits obtained under conditions of spark and high frequency discharge were also observed. In the latter a sleeve electrode was used round the discharge tube connected to a high frequency tension source, the cathode being earthed as usual. Under these circumstances, one gets a fairly intense beam through the canal which to judge by the light emitted by it, consists of hydrogen particles. That this was not a more rectification effect was shown by the null reading in the D.C. ammeter connected to the cathode. A glass plate exposed to these rays showed the usual form of deposit (Pl. 6). Under conditions of spark discharge, we get short intense streamers whitish red in color which have been regarded to consist of slow metallic ions. Glass plates exposed to these have been known to show deposits (Bareford 1935) but any structure in them does not find mention. On exposing a plate to these, one obtains a deposit which shows itself as a single well-defined ring which is slightly bigger than the aperture of the canal, when the plate is kept practically in contact with the cathode. This is very similar to the one obtained with positive rays at this distance. Some observations during these experiments suggested that the shape and material of the anode might have some influence on the deposit formation. Subsequent experiments with canal rays, with different anode materials of the different shapes showed the absence of any such influence. It may be mentioned that the condition of the discharge does affect the deposit formation and distorted ring patterns are obtained under conditions where there is an unsteady discharge or when it creeps under the electrode. Observations were also made by splitting the canal into two by an aluminium plate. Two patterns were obtained corresponding to the two portions of the canal though overlapping took place to a certain extent. That the deposits take the shape of the positive ray beam was again clearly shown on exposing a plate tilted at 45° with the plane of the cathode when elliptically-disposed rings were obtained (Pl. 20).

The cathode faces, on the observation as well as the discharge side (Pl. 27) sometimes showed deposits with a structure. A possibility of some type of reflection of the positive ray particles between the exposed plate and the cathode surface was suggested. To test this a fine mesh was introduced between the canal and the plate. The deposits obtained (Pl. 21) consisted of fine spots which were themselves distributed in the form of an annular zone. This incidentally shows the absence of any creeping on the part of the deposits. This was further confirmed by heating a plate on which this

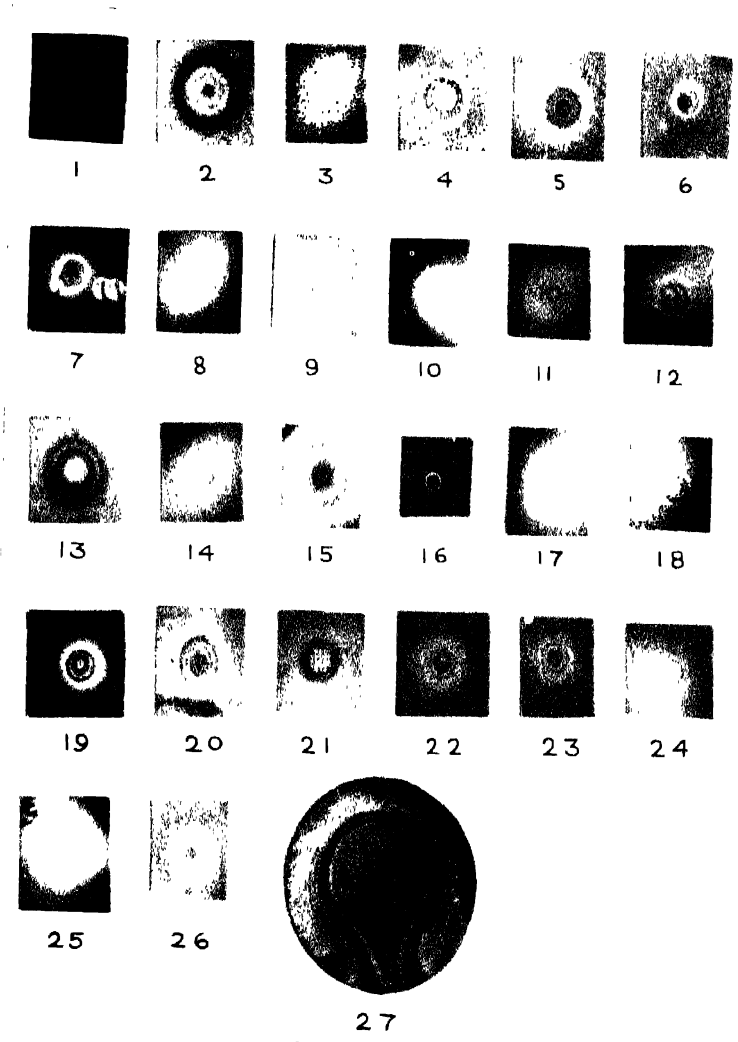
ring formation was obtained directly over a burner when no change was found in their disposition. This observation, however, does not preclude the possiblity of 'creeping' while in the act of formation This, we believed, is shown by the mesh experiment

The variation in the structure of the deposits with the energy of the bombarding rays is interesting. This was investigated under both the modes of introducing the piecin vapour (*vide infra*). In the case where it is streamed along with the gas, one finds that at low voltage (both 4 KV), the plate shows a translucent spot in the centre surrounded by a thin deposit which gradually fades towards the edges (Pl. 6) Near the edge of the central spot, one can just see a faint ring. This gets more and more marked till about 7 KV there is a sharp ring formed there. As one increases the voltage the diameter of the central spot decreases and the rings stand out prominently on the back ground (8 KV) (Pl. 8). When viewed in reflected light one observes a number of delicate regular rings almost like interference rings except for their colour In the case of the alternative mode of introducing the piecin plates 10, 11, 12, 13, show the results for voltages 4, 6, 8, 10 KV respectively. Here the structure is perceptible even at low voltages of the order of 1 KV. With increase of voltage the number of rings increases and also the diameter apparently. A measurement of the diameter of the rings in these plates shows, however, that with increase of voltages the rings are successively destroyed starting from the centre and the maximum of intensity shifts gradually from the innermost to the outer rings. This probably is due to the thermal effect of the bombarding rays and we infer that at very high voltages and long times of exposure the structure should be absent and the intensity of the deposits also must become small. This was supported by observation of the deposits obtained with positive rays of carbon dioxide at 16 KV. Thus it is possible that there is an optimum voltage and time of exposure with which the structure is best obtained. The variation in these deposits with different times of exposure lends further support to this deduction. Plates 11, 17, 18, show the deposits obtained with times of exposure 12 minutes 1 hour and 2½ hours Here also we can see the progressive destruction of the rings and the gradual shifting of the maximum of intensity towards the outer rings. It may be mentioned that variation of the earth current is without effect on the structure and what is more curious, on the intensity of the deposits. Plates 11, 10, are obtained with earth currents of 1. mA and 0.2 ma respectively.

Variation of the distance of the bombarded plate from the cathode between values ranging from 0 to 20 mms. was next tried in another series of observations. The deposit, when the plate is kept in contact with the cathode, shows itself as a single ring (Pl. 16) not unlike that obtained under spark discharge. As the distance of the plate from the cathode is increased (Pl. 25) the characteristic multiple ring structure makes its appearance. At greater distances the rings obtained are less distinct, they naturally have greater dimensions

(Pl. 15) but they lose regularity to some extent. In most of the above experiments the plates were kept at a distance of 5 mms. from the cathode. It may be mentioned that the ring effect was first observed on a plate at a distance of 110 mms. from the cathode. A reference may, however, be made to a phenomenon which was observed (Chiplonkar, 1939 b) during the course of this work, which appears to be of interest for the purposes of the present investigation. In some experiments 'gas streaming' was not used but picein vapor was added from time to time. Each such addition was followed by a rapid rise in the voltage across the tube though no change was observed in the earth current. This was presumbaly an effect of the so-called 'clean-up' since the voltage becomes a rough index of the pressure in the tube when the discharge current remains constant. This rapid rise of the voltage was followed by a subsequent gradual decrease which was marked by a number of periodic fluctuations of small magnitude. Significant changes in the colour of the discharge accompany these fluctuations. In the absorption regime when the voltage is rising, the colour is that of hydrogen pure rose red, in the desorption regime, when the voltage is falling, there is a preponderence of bluish white color. This observation suggests that when the release of the absorbed hydrogen takes place, the hydro-carbons accompany it It has been mentioned before that every value of the external voltage has got a characteristic ring structure corresponding to it. The idea, therefore, suggested itself that the multiplicity of the ring structure might be due to these fluctuations. In all the experiments thus far mentioned, in which streaming was not used, the voltage was kept constant by continuously manipulating the pressure. In one experiment this was not done and the voltage was allowed to fluctuate without interference to test the above hypothesis. The exposed plate (Pl. 22), however, failed to show any increase in the number of rings. The deposit was kept under observation, while in the course of formation, to see if it showed corresponding changes in the increase of intensity in the two stages of absorption and desorption. The difference was not very marked but one could see that the increase in the intensity of the deposits took place in the latter but not in the former stage.

Observations with electron beams recorded by other workers (*vide supra*) suggested the possibility of a structure in the positive ray beam itself. Such a structure is known in the case of positive rays and has been generally ascribed to the effect of stray magnetic fields. To test whether a similar structure was responsible for the deposits described here, a transverse magnetic field was applied on the discharge side of the canal (Konigsberger and Kutschewski, 1910) which extended practically over the whole length of the cathode dark space In this case, the discharge was twisted and struck a place in the middle of the discharge tube where glass fluorescence was obtained. Here a dark brown deposit was produced. The deposit obtained on the plate is shown (Pl. 24). Similar results were obtained with different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magnetising currents in the electro-magnet. Observations were also made with a receptacle plate raised to 220 volts when similar results were obtained

DISCUSSIONS

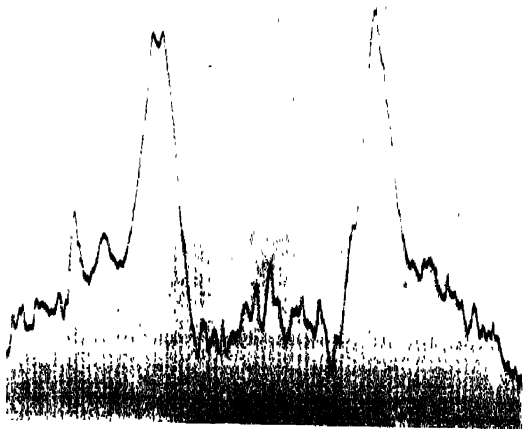
The general nature of the phenomenon is shown by its appearance under greatly varied conditions, with different bombarded materials, different gases in the discharge tube etc. It shows, however, a definite dependence on the excitation voltage, the structure making its appearance above a certain value of the latter. This value, however, varies from tube to tube and seems to depend on the way in which the deposit forming material is introduced as well (vide infra p 3). For voltages below this there is deposition but no structure. Certain experiments tend to show that for very high voltages also, the structure can be absent. The fact that the deposits follow the shape of the beam, form on plates placed in contact with the cathode, get distorted under unsteady discharge, fairly make it certain that they originate in the discharge space.

It is generally accepted that the positive ray particles suffer no collisions in their passage across the cathode dark space which result in the transfer of kinetic energy (Chaudhri and Oliphant 1932). To explain the kinetic energy of the hydrocarbon particles one is left only with two possibilities (1) they are carried along the positive rays through some type of association or (2) form positive rays themselves Two possible types of association are due to (*a*) electron exchange or (*b*) due to the formation of loose chemical complexes. A process of electron exchange takes place in which an atom gets neutralised and fresh ion produced without there being necessarily a transfer of the kinetic energy. Kallman and Rosen (1930) have shown that the probability of transfer depends on N−I where N is the neutralising energy of the ion and I the ionisation potential. It is probably this type of reaction that makes it possible to get canal rays of mercury or iodine by the addition of traces of hydrogen. Another possible type of association has already been suggested, *i.e.*, the formation of loose complexes between hydrogen and adsorbing hydrocarbon. The reason why some type of association is suggested is based on the observation (1) the dependence of the intensity of the deposits on the gas in the discharge tube (2) non-influence of the amount of hydrocarbon vapours on the intensity. One can explain, on this basis, the above mentioned dependence in terms of the case of association between the gas and the hydrocarbons. Hydrocarbon particles are known to occur in the canal rays. On the other hand one expects that the presence of the hydrocarbon, whatever the type of association, will appreciably affect the velocity distribution among the canal rays. Investigations on the Doppler effect show that such an effect exists when a foreign gas like helium (Wien 1927 (c) etc., is introduced into the discharge space but not when it is only introduced in the observation chamber. In the deposit phenomenon under consideration, it has been shown that introducing the picein in the observation chamber increases enormously

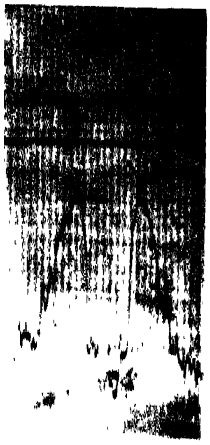
the intensity of the deposits There is no doubt that there is considerable diffusion of this vapour to the discharge side, and the increase in intensity is probably due to the fact that by this mode it is introduced directly into the dark space where the beam formation takes place. In the other mode, there is the possibility of its being deposited before it comes in the dark space. The considerations thus far given do not preclude the possibility of the existence of the positive rays of the hydro-carbons but make it less likely. Raether (1933) has observed that these deposits are not found when the positive ray beam is passed through an analysing field prior to the impact. The evidence that has been given thus far, especially that with transverse magnetic field indicates that the phenomenon is not characteristic of the charged particles

To find an explanation for the peculiar ring structure observed, one has to settle beforehand whether it is the result of a primary action due to an inherent structure in the beam or a secondary action caused by a redistribution of these deposits through the agency of either the impacting rays or merely surface forces called into play by condensation. Data on molecular beams, do not lend support to this last possibility (Cockroft, 1928). The second hypothesis assumes that a deposit formed on the plate, suffers a redistribution into the characteristic ring structure by some specific action of the impacting rays When positive rays strike a surface in vacuum, many types of reactions can take place involving various kinds of energy exchanges. These range from the very small transfer of energy accompanying reflection to the violent destruction of the surface by bombardment. The production of thermal or chemical action, the emission of electrons, positive particles (Wien, 1927, (a)) or under special conditions the release of occluded gases (Johnson, 1930) from the surface comprise the main reactions produced by canal ray bombardment. That the redistribution does not mean any surface motion has been demonstrated by the mesh experiments. Observations on the tilted plate (*vide infra*) rule out the possibility of selective reflection, for the presence of this effect would have brought about a difference in the intensity of the deposits in the different regions. The existence of rings on both metallic and non-metallic plates invalidates the view that it is due to characteristic charging up of the surface. The possibility of chemical action is ruled out by the generality of the phenomenon. We are therefore only left with the possibility of mechanical action. The existence of such a mechanical action is shown by the observations of Stark and Wendt (1913) who report that glass plates exposed to positive ray bombardment develop a depression at the point of impact due to a partial penetration by the rays. Berliner, (1926) has shown the possibility of microscopic explosions of the loose metallic complexes (in which form the impacting ions are held bound on the cathodic surface) due to positive ionic bombardment. Bush and Smith (*ibid*) explain this on the supposition that the bound ions on the cathode reach such a high pressure as to become unstable. It is not unlikely that a similar effect is taking place

Fig 1

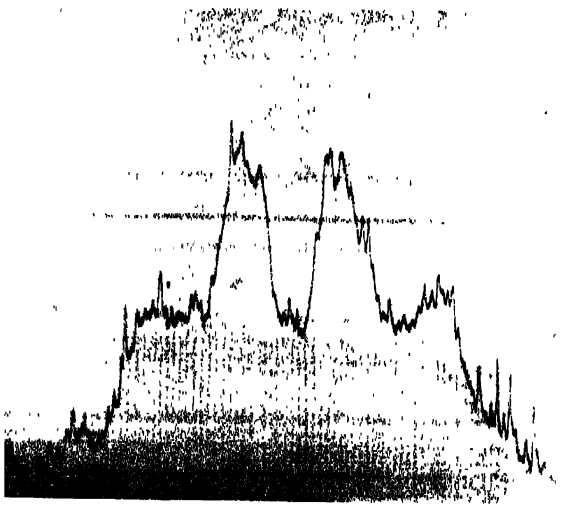


Microphotometer curve of the plate showing the deposit of Fig 1B Plate IA Magnification 1 X 10



Microphotometer curve of the plate showing the deposit of Fig 5, Plate IA) Magnification 1 X 3

Fig 3



Microphotometer curve of a plate showing the deposit obtained with canal rays of CO_2 with 6 KV, 60 m a d = 0.5 cms, T = 2 minute, Magnification 1 X 10

here, for the observations given in this paper clearly show that the deposition is accompanied by adsorption effects. Accordingly we can think of the deposition as proceeding along the following stages: (1) a primary deposition of the particles from the associated beam on the bombarded surface, (2) adsorption of the impacting ions by this primary deposit which ends in (3) a mechanical explosion in which the deposit forming material is scattered. On account of the central symmetry of the primary deposit, it is reasonable to suppose that the secondary deposition will also show a similar symmetry. This hypothesis, although it suggests a likely reaction, does not explain the ring structure. The dependence on the nature of the gas in the discharge tube, the existence of a threshold value etc. make it probable that the phenomenon under consideration, is closely bound up with the allied phenomenon of cathode sputtering.

There is the other probability of an inherent structure in the beam of the hydrocarbon particles themselves. Such a structure is known to exist in the case of electron beams, brought about by a variety of causes depending on the form and disposition of the apparatus. Thus McFarlane (1936) reports that a beam of electrons passed through earthed slits shows a structure which he finds reason to ascribe to certain charges developed by the irregularities on the slits. Curran (1936) reports a case in which this was brought about by the geometry of the collimating slits. Lastly we have the inherent structure (Clay, 1928) showed by high velocity electron beams in Röntgen ray tubes. Rüchardt (Wien, 1927, b) has mentioned that a structure in a positive ray beam is brought about by the action of stray magnetic fields. This suggested the possibility of an inherent structure in the positive ray beam. The experiments with the transverse magnetic field, however, show that the ring structure is not to be ascribed to any similar effect. The distortion of the rings in the case of an unsteady discharge shows, however, that the phenomenon is intimately connected with the process of beam formation in the cathode dark space.

Note on the microphotometer curves.—The microphotometer curves of the original plates on which the deposits were formed were taken at the suggestion of Dr. Asundi on a Zeiss recording Microphotometer. The plates were run on the microphotometer with a point source along a diameter of the ring deposits. The curves, therefore, represent the distribution of the particle-density along the diameter and exhibit in a remarkable way, the multiplicity in the ring structure of these deposits.

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(a) p. 458, 463, 475, 539
(b) p. 576, 527.
(c) p. 655

EXPLANATION OF THE PLATES IA, IB

All the photographs except plate (23) show the deposits as seen in reflected light of a size slightly greater than the original. Plate (23) depicts a direct contact print of the glass plate on which the deposit was obtained. The same plate as seen in reflected light is shown for comparison in plate (14). In the following data, unless specific mention is made to the contrary the plate exposed should be taken to be a smooth glass plate. Plates marked W. S. are taken with picein vapour streamed along with the gas; all the rest with the other mode of introducing it (*vide infra*) 'd' represents the distance of the plate behind the cathode, T the time of exposure. All the other symbols are self explanatory.

Pl. 1. Ground glass plate, canal rays of hydrogen, 3 KV, 1.2 ma, d = 1.5 cms. T = 90 min.

Pl. 2. Polished graphite, canal rays of hydrogen 6.0 KV, 1.0 ma, d = 0.5 cms. T = 60 min.

Pl. 3. Smooth glass plate, canal rays of hydrogen 7 KV, 1.0 ma, d = 0.5 cms. T = 150 min.

Pl. 4. Canal rays of oxygen, 6 KV, 1.0 ma, d = 0.5 cms. T = 20 min.

Pl. 5. Canal rays of nitrogen, 8 KV, 0.9 ma, d = 0.5 cms. T = 14 min.

Pl. 6. High frequency discharge in hydrogen, 0.5 ma, d = 0.5 cms. T = 32 min.

Pl. 7. Canal rays of air, 6 KV, 0.8 ma, d = 0.4 cms. T = 1.3 min. split canal.

Pl. 8. W. S. Canal rays of hydrogen, 8 KV, 1.0 ma, d = 0.5 cms. T = 30 min.

Pl. 9. W. S. Canal rays of hydrogen 4.0 KV, 1.0 ma, d = 0.5 cms. T = 130 min.

Pl. 10. Canal rays of hydrogen, 4.0 KV, 0.8 ma, d = 0.5 cms. T = 20 min.

Pl. 11. Canal rays of hydrogen, 6. KV, 1.0 ma, d = 0.5 cms. T = 12 min.

Pl. 12. Canal rays of hydrogen, 8 KV, 1.0 ma, d = 0.5 cms. T = 20 min.

Pl. 13. Canal rays of hydrogen, 10 KV, 0.8 ma, d = 0.5 cms. T = 20 min.

Pl. 14. W. S. Canal rays of hydrogen, (Picein predominating), 3 KV, 1.0 ma, d = 0.5 cms. T = 120 min.

Pl. 15. Canal rays of hydrogen, 5 KV, 0.5 ma, d = 2.0 cms. T = 2[illegible] min.

Pl. 16. Canal rays of hydrogen, 6. KV, 0.5 ma, d = 0.1 cms. T = 20 min.

Pl. 17. Canal rays of hydrogen, 6 KV, 1.0 ma. d = 0.5 cms. T = 60 min.

Pl. 18. Canal rays of hydrogen, 6 KV, 1.0 ma, d = 0.5 cms. T = 120 min.

Pl. 19. Canal rays of hydrogen, 6 KV, 0.2 ma, d = 0.5 cms. T = 20 min.

Pl. 20. Canal rays of hydrogen, 3 KV, 1.2 ma, d = 0.0 cms. T = 120 min, tilted at 45^0 to face of canal.

Pl. 21. Canal rays of hydrogen, 8 KV, 0.8 ma, d = 1.0 cms. mesh 0.5 cms. from cathode. T = 50 min.

Pl. 22. Canal rays of hydrogen, fluctuating voltage, d = 0.5 cms. T = 180 min.

Pl. 24. Canal rays of hydrogen, 6.0 KV, 1.0 ma, d = 0.5 cms. T = 42 min with transverse magnetic field.

Pl. 25. Canal rays of hydrogen, 6 KV, 0.5 ma, d = 0.5 cms. T = 20 min

Pl. 26. Canal rays of air, 4 KV, 1.2 ma, d = 0.5 cms. T = 120 min.

Pl. 27. Cathode face on discharge side